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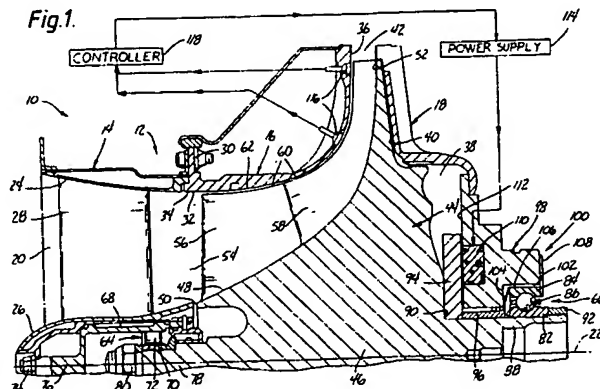
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54 **Turbomachine with active tip-clearance control.**

57 A turbomachine (10) including a case (12), a rotor (44), a plurality of rotor blades (56,58) on the rotor (44), each having a blade tip (60), a shroud (16) around the rotor blade tips (60), and bearing means (64,66) mounting the rotor (44) on the case (12) for rotation about a centreline (22) of the case (12) and for bodily-shiftable movement in the direction of the centreline (22). The rotor blade tips (60) and an inside wall (32) of the shroud (16) flare radially outwards in the direction of the centreline (22) so that, when the rotor (44) moves in the direction of the centreline (22) towards the shroud (16), a clear-

ance gap (62) between the blade tips (60) and the inner wall (32) of the shroud (16) decreases and vice versa. An electromagnetic actuator (100) on the case (12) magnetically attracts a thrust plate (94) on the rotor (44) against a net dynamic force produced on the rotor (44) during the operation of the turbomachine (10). A control system (118) of the actuator (100) controls the magnetic attraction of the actuator (100) in response to signals from a position sensor (116) measuring the actual magnitude of the clearance gap (62), so as to maintain the actual clearance gap (62) at a predetermined magnitude.

Fig.1.



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This invention relates to tip-clearance control in gas turbine engines as specified in the preamble of claim 1, for example as disclosed in US-A-1,823,310.

Minimizing leakage around the tips of compressor and/or turbine blades in gas turbine engines or other turbomachines improves efficiency. In most prior active tip-clearance control proposals, a shroud or surface thereof is moved towards and away from blade tips during engine operation to maintain a predetermined tip clearance. For example, many prior proposals include a thermally-responsive shroud around blade tips, which shroud expands and contracts in accordance with selective exposure to hot gas behind the shroud. In another proposal, the inside diameter of a segmented shroud is controlled by balancing high-pressure air in a chamber behind the shroud against normal gas pressure on the opposite side of the shroud in a gas flow path of the turbomachine. In still other proposals, mechanical linkages and eccentric mechanisms bodily shift annular shrouds longitudinally towards and away from the blade tips. And in yet another proposal, a shroud wall of a radial flow compressor is connected to a static support through a flexible diaphragm which distorts under thermal and pressure loading to effect movement of the shroud wall. A gas turbine engine or turbomachine according to this invention includes novel, active tip-clearance control apparatus.

A turbomachine according to the present invention is characterised by the features specified in the characterising portion of claim 1.

This invention is a new improved turbomachine having a case, a shroud rigidly supported on the case, and a rotor supported on the case for rotation about a centreline of the case and for bodily-shiftable movement in the direction of the centreline. The rotor has a plurality of blades thereon, the tips of which flare radially outwards. The shroud has an outwardly-flared inner wall facing the blade tips and the gas flow path of the turbomachine so that bodily-shiftable movement of the rotor towards the shroud decreases the clearance between the blade tips and the inner wall of the shroud. During operation of the turbomachine, a net dynamic force on the rotor continuously urges the rotor in the direction corresponding to minimum clearance between the blade tips and the shroud. An actuator on the case includes an electromagnet and a control system for modulating the magnetic attraction of the electromagnet on a thrust plate rigidly attached to the rotor. The magnetic attraction of the actuator is opposite in direction to the net dynamic force on the rotor. The control system includes position sensors on the case which provide signals corresponding to the instantaneous clearance between the blade tips and the shroud.

The control system modulates the magnetic attraction of the actuator in response to the signals from the position sensors to maintain a substantially constant clearance between the shroud and the blade tips.

The invention and how it may be performed are hereinafter particularly described with reference to the accompanying drawings, in which:

Figure 1 is a fragmentary longitudinal sectional view of a radial flow turbomachine according to this invention; and

Figure 2 is a fragmentary longitudinal sectional view of an axial flow turbomachine according to this invention.

Referring to Figure 1, a turbomachine in the form of a radial flow compressor 10 includes a case 12 having a front frame 14, a shroud 16, and a back plate 18, all rigidly connected together. An annular air inlet 20 of the compressor, symmetrical about a longitudinal centreline 22 of the case, is defined between an outer wall 24 of the front frame and an inner dome 26 of the front frame. A plurality of radial struts support the inner dome 26 relative to the outer wall 24 and define guide vanes in the air inlet 20, only a single strut 28 being visible in Figure 1.

The shroud 16 has a flange 30 for attachment to the front frame 14 and an inner wall 32 which flares radially outwards from a circular forward edge 34 to an outer circumferential edge 36. The back plate 18 of the case is symmetrical about the centreline 22 and is spaced axially from the shroud 16 so that a rotor chamber 38 is defined between the inner wall 32 of the shroud and an inner surface 40 of the back plate. An annular discharge 42 from the rotor chamber is defined between the circumferential edge 36 and the inner surface 40 of the back plate and may be surrounded by a diffuser (not shown) and a scroll chamber (not shown).

A rotor 44 of the compressor 10 is aligned on the centreline 22 in the rotor chamber 38 and includes a hub 46 having an outer wall 48 facing the inner wall 32 of the shroud and flaring radially outwards from a front edge 50 of the rotor to a circumferential outer edge 52 of the rotor. The outer wall 48 and the inner wall 32 co-operate in defining therebetween an annular, outwardly-flaring gas flow path 54 extending from the inlet 20 to the discharge 42. A plurality of integral full blades and integral splitter blades of the rotor are disposed in the gas flow path 54, only a single full blade 56 and a single splitter blade 58 being visible in Figure 1. Each of the blades 56, 58 has an outwardly-flaring tip 60 spaced from the inner wall by a clearance gap 62 illustrated in exaggerated fashion for clarity in Figure 1.

The rotor 44 is supported on the front frame 14 by a front bearing assembly 64 and on the back

plate 18 by an aft bearing assembly 66 for rotation about the centreline 22 and for bodily-shiftable movement in the direction of the centreline. The front bearing assembly 64 includes a cup-shaped outer race 68, an annular inner race 70, and a plurality of rollers 72 therebetween. The outer race 68 is clamped to the dome 26 by a nut 74 on a stem 76 of the outer race 68. The inner race 70 is clamped on a cylindrical front extension 78 of the rotor 44 by a nut 80. In the direction of centreline 22, the rollers 72 are effectively unrestrained for small excursions of the order of 0.762 mm (0.030 inch). Therefore, the rollers 72 also support the front extension 78 on the dome 26 for small excursions of bodily-shiftable movement in the direction of the centreline 22.

The aft bearing assembly 66 includes an inner race 82, an outer race 84 and a plurality of anti-friction bearing balls 86 therebetween. The bearing balls 86 seat in respective grooves in the inner and outer races 82, 84 and, accordingly, prevent relative movement between the races in the direction of centreline 22. The inner race 82 is clamped on an aft extension 88 of the rotor 44 against a shoulder 90 on the hub 46 by a nut 92 with an annular thrust plate 94 and a tubular spacer 96 disposed on the aft extension 88 between the shoulder 90 and the inner race 82. The thrust plate 94 is made of ferromagnetic material. The aft extension 88 may be adapted for connection to a turbine shaft (not shown) for driving the rotor 44.

An annular housing 98 of an electromagnetic actuator 100 is rigidly connected to the back plate 18 and, consequently, to the case 12 and includes a counter-bore 102 aligned on the centreline 22. The outer race 84 of the aft bearing assembly 66 is disposed in the counter-bore 102 with a spring washer 104 between the outer race 84 and the bottom of the counter-bore 102 and with a squeeze-film damping chamber defined in an annular clearance 106, illustrated in exaggerated fashion for clarity in Figure 1, around the outer race 84.

The annular clearance 106 permits relative movement to occur between the actuator housing 98 on the one hand and the aft bearing assembly 66 and the rotor 44 on the other hand in the direction of the centreline 22. A retainer 108 on the actuator housing 98 limits movement of the outer race 84 to the right, as seen in Figure 1, under the influence of the spring washer 104 and, therefore, defines a retracted position of the rotor 44 relative to the shroud 16. In the retracted position of the rotor, the gap 62 between the blade tips 60 and the inner wall 32 of the shroud assumes a maximum dimension of the order of 0.381 mm (0.015 inch).

The actuator 100 further includes an annular electromagnet 110 on the housing 98 flush with a side 112 thereof facing the thrust plate 94. The

electromagnet includes a metal core and a wire coil connected to a power supply 114. When the electromagnet 110 is turned on, the power supply induces a current in the coil which produces a magnetic flux field which, in turn, intercepts the ferromagnetic thrust plate 94 and attracts the thrust plate and, consequently, the rotor 44 to the right towards the side 112 of the housing 98, as seen in Figure 1.

The magnetic attraction of the actuator 100 is variable in accordance with the current flow through the coil of the electromagnet 110. A control system of the actuator 100 for modulating the power supply 114 and the magnetic attraction of the electromagnet includes a plurality of position sensors 116 on the shroud 16 and a programmable controller 118 connected to the sensors and to the power supply 114 for modulating the latter in response to signals from the sensors.

When the compressor is operating, a net dynamic force on the rotor 44 urges the rotor to the left as seen in Figure 1, so that the blade tips 60 are urged towards the inner wall 32 of the shroud. The net dynamic force is the result of migration of high-pressure air from the discharge 42 to the space behind the rotor and urges the rotor to an innermost position (not shown) achieved when the washer 104 is flattened between the bottom of the counterbore 102 and the outer race 84 of the bearing assembly 66. Clearance between the blade tips and the shroud is minimum in the innermost position of the rotor. The spring washer 104 also acts to keep the aft bearing assembly 16 loaded in the same direction as the direction of the magnetic attraction regardless of the magnetic attraction on the thrust plate.

To control the magnitude of the gap 62, the sensors 116 provide signals to the programmable controller 118 characteristic of the instantaneous, real-time magnitude of the gap 62. The controller compares the real-time magnitude of the gap with a schedule of magnitudes calculated to maximize the efficiency of the compressor. Based on the comparison, the controller modulates the power supply 114 to increase or decrease the magnetic attraction of the electromagnet 110 on the thrust plate 94 to effect bodily-shiftable movement of the rotor 44 towards or away from the inside wall 32 of the shroud 16.

Referring now to Figure 2, a turbomachine in the form of a fragmentarily-illustrated axial flow gas turbine engine 120 includes a case 122 having an outer wall 124 and an inner wall 126 which define therebetween an annular compressed-air plenum 128. An annular combustor 130 in the compressed-air plenum 128 produces a continuous stream of hot gas which discharges from the combustor 130 through a stationary nozzle ring 132. The nozzle

ring 132 defines an upstream end of an annular gas flow path 134 of the engine.

A turbine rotor 136 of the engine 120 includes a turbine wheel 138 having a cylindrical hub 140 connected to a tubular rotor shaft 142 for rotation as a unit with the shaft 142 about a longitudinal centreline (not shown) of the engine. A fragmentarily-illustrated cylindrical hub 144 of a second turbine wheel (not shown) is similarly rigidly connected to the rotor shaft 142. The turbine wheel 138 has a circumferential array of turbine blades thereon in the gas flow path 134, only a representative blade 146 being visible in Figure 2. The turbine blades each have a radially outwardly-flaring blade tip 148 thereon in close proximity to a radially outwardly-flaring inner wall 150 of an annular shroud 152 rigidly supported on the case 122.

A bearing assembly 154 of the engine 120 includes an inner race 156 on the rotor shaft 142 clamped by a nut 158 against a shoulder 160 of the rotor shaft 142 with an annular thrust plate 162 and additional seal runners and spacers between the inner race and the shoulder. The thrust plate 162 is made of ferromagnetic material. An outer race 164 of the bearing assembly 154 is disposed around the inner race 156 with a plurality of anti-friction bearing balls 166 therebetween. The bearing balls 166 seat in grooves in the races and, accordingly, prevent relative bodily-shiftable movement from occurring between the inner and outer races 156, 164 in the direction of the longitudinal centreline of the engine.

An annular support 168 is bolted to a flange 170 integral with the inner wall 126 of the engine case. An annular actuator housing 172 of an electromagnetic actuator 174 is rigidly connected to the support 168 and includes an inner cylindrical wall 176 aligned on the longitudinal centreline of the engine, an annular surface 178 facing the thrust plate 162, and an annular shoulder 180 at an inward end of the cylindrical wall 176.

The outer race 164 of the bearing assembly 154 is disposed in the annular housing 172 adjacent the cylindrical wall 176 with a spring washer 182 between the outer race 164 and the annular shoulder 180 on the housing 172. A squeeze-film damping chamber is defined in an annular clearance 184, illustrated in exaggerated fashion for clarity in Figure 2, around the outer race 164. The annular clearance 184 permits relative movement to occur between the actuator housing 172 on the one hand and the bearing assembly 154 and the rotor 136 on the other hand in the direction of the longitudinal centreline of the engine 120.

A retainer 186 on the actuator housing 172 limits movement of the outer race 164 to the right, as seen in Figure 2, under the influence of the

spring washer 182 and, therefore, defines a retracted position of the rotor 136 relative to the shroud 152. In the retracted position of the rotor, the gap between the blade tips 148 and the inner wall 150 of the shroud assumes a maximum dimension of the order of 0.762 mm (0.030 inch).

The actuator 174 further includes an annular electromagnet 188 on the housing 172 flush with the surface 178 thereof facing the thrust plate 162. The electromagnet 188 includes a metal core and a wire coil connected to a power supply 190. When the electromagnet 188 is turned on, the power supply 190 induces a current in the coil which produces a magnetic flux field which, in turn, intercepts the ferromagnetic thrust plate 162 and attracts the thrust plate and, consequently, the rotor 136 to the right towards the annular surface 178, as shown in Figure 2.

The magnetic attraction of the actuator 174 is variable in accordance with the current flow through the coil of the electromagnet 188. A control system of the actuator for modulating the power supply 190 and the magnetic attraction of the electromagnet 188 includes a plurality of position sensors 192 on the shroud 152 and a programmable controller 194 connected to the sensors 192 and to the power supply 190 for modulating the latter in response to signals from the sensors 192.

When the engine is operating, a net dynamic force on the rotor 136 urges the rotor to the left, as seen in Figure 2, to an innermost position (not shown) achieved when the washer 182 is flattened between the annular shoulder 180 and the outer race 164 of the bearing assembly 154. Clearance between the blade tips and the shroud is minimum in the innermost position of the rotor. The net dynamic force on the rotor is due to dynamic forces on a compressor, not shown, of the engine 120 connected to the shaft 142. The spring washer 182 also acts to keep the bearing assembly 154 loaded in the same direction as the direction of magnetic attraction, regardless of the magnetic attraction on the thrust plate 162.

To control the magnitude of the gap between the blade tips 148 and the shroud wall 150 when the engine is operating, the sensors 192 provide signals to the programmable controller 194 characteristic of the instantaneous, real-time magnitude of the gap. The controller compares the real-time magnitude of the gap with a predetermined schedule of magnitudes. Based on the comparison, the controller modulates the power supply 190 to increase or decrease the magnetic attraction of the electromagnet 188 on the thrust plate 162 to effect bodily-shiftable movement of the rotor 136 in the direction of the longitudinal centreline of the engine.

Claims

1. A turbomachine (10) comprising: a case (12) having a longitudinal centreline (22), an annular shroud (16) rigidly attached to said case (12) having an inner wall (32) defining a side of an annular gas flow path (54) of said turbomachine (10) around said longitudinal centreline (22) which flares radially outwards in a downstream direction of said gas flow path (54), a rotor (44) having a plurality of rotor blades (56,58) thereon, bearing means (64,66) mounting said rotor (44) on said case (12) with said rotor blades (56,58) in said gas flow path (54) for rotation about said longitudinal centreline (22) and for bodily-shiftable movement in the direction of said longitudinal centreline (22) in a first direction towards said shroud (16) and in an opposite second direction away from said shroud (16), said rotor (44) being subjected to a net dynamic force in said first direction during operation of said turbomachine (10), each of said rotor blades (56,58) having a blade tip (60) flaring radially outwards in the downstream direction of said gas flow path (54) and co-operating with said inner wall (32) of said shroud (16) in defining a clearance gap (62) therebetween decreasing in response to bodily-shiftable movement of said rotor (44) in said first direction and increasing in response to bodily-shiftable movement of said rotor (44) in said second direction, and an actuator means for producing bodily-shiftable movement of said rotor (44) in said second direction, characterised in that said actuator means includes a ferromagnetic thrust plate (94) rigidly connected to said rotor (44); an electromagnet means (100) on said case (12) which produces a magnetic flux field when activated which intercepts said thrust plate (94) and magnetically attracts said rotor (44) in said second direction; position-sensing means (116) on said case (12) operative to generate an electrical signal during operation of said turbomachine (10) which corresponds to the instantaneous magnitude of said clearance gap (62) between said rotor blade tips (60) and said inner wall (32) of said shroud (16); and control means (114,118) connected to said electromagnet means (100) and to said position-sensing means (116) which is operative to modulate the magnetic attraction of said electromagnet means (100) in response to said signals from said position-sensing means (116) so as to maintain a substantially constant clearance gap (62) between said rotor blade tips (60) and said inner wall (32) of said shroud (16) during the operation of said turbomachine (10).
2. A turbomachine (10) according to claim 1, in which said bearing means mounting said rotor (44) on said case (12) includes a bearing assembly (66) comprising: an inner race (82) rigidly attached to said rotor (44), an outer race (84), and a plurality of anti-friction elements (86) between said inner race (82) and said outer race (84) permitting relative rotation between said inner race (82) and said outer race (84) and preventing relative bodily-shiftable movement from occurring between said inner race (82) and said outer race (84) in the direction of said longitudinal centreline (22).
3. A turbomachine (10) according to claim 2, in which there is a spring means (104) located between said case (12) and said outer race (84) of said bearing assembly (66) which biases said bearing assembly (66) and said rotor (44) in said second direction and maintains a net force on said bearing assembly in said second direction regardless of the magnetic attraction exerted by said electromagnet means (100) on said thrust plate (94).
4. A turbomachine (10) according to claim 3, in which said spring means is an annular spring washer (104) between said case (12) and said outer race (84) of said bearing assembly (66), which spring washer (104) has a flattened condition which defines an innermost position of said rotor (44) relative to said shroud (16) in which said clearance gap (62) between said rotor blade tips (60) and said inner wall (32) of said shroud (16) is at a minimum.

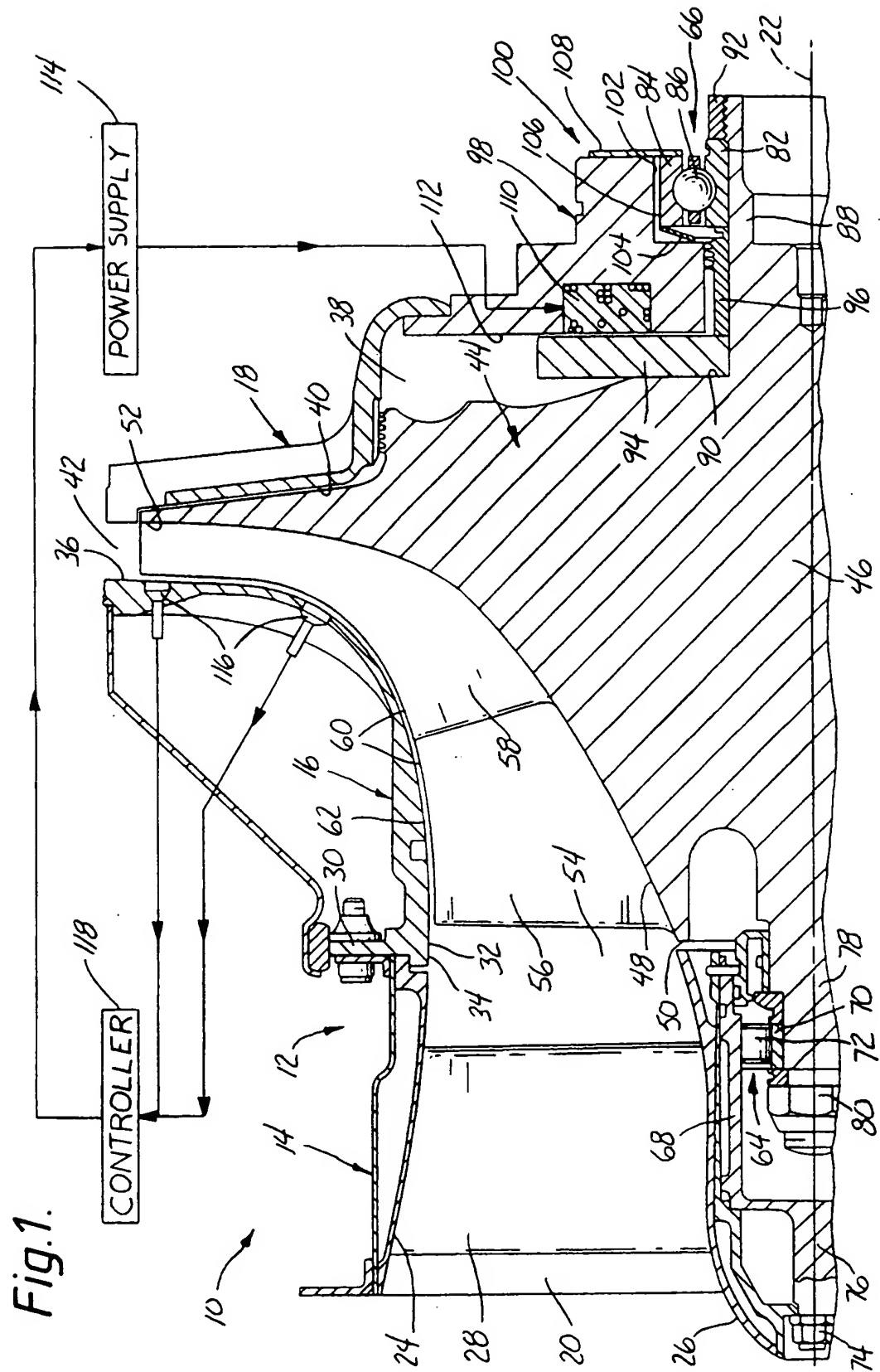
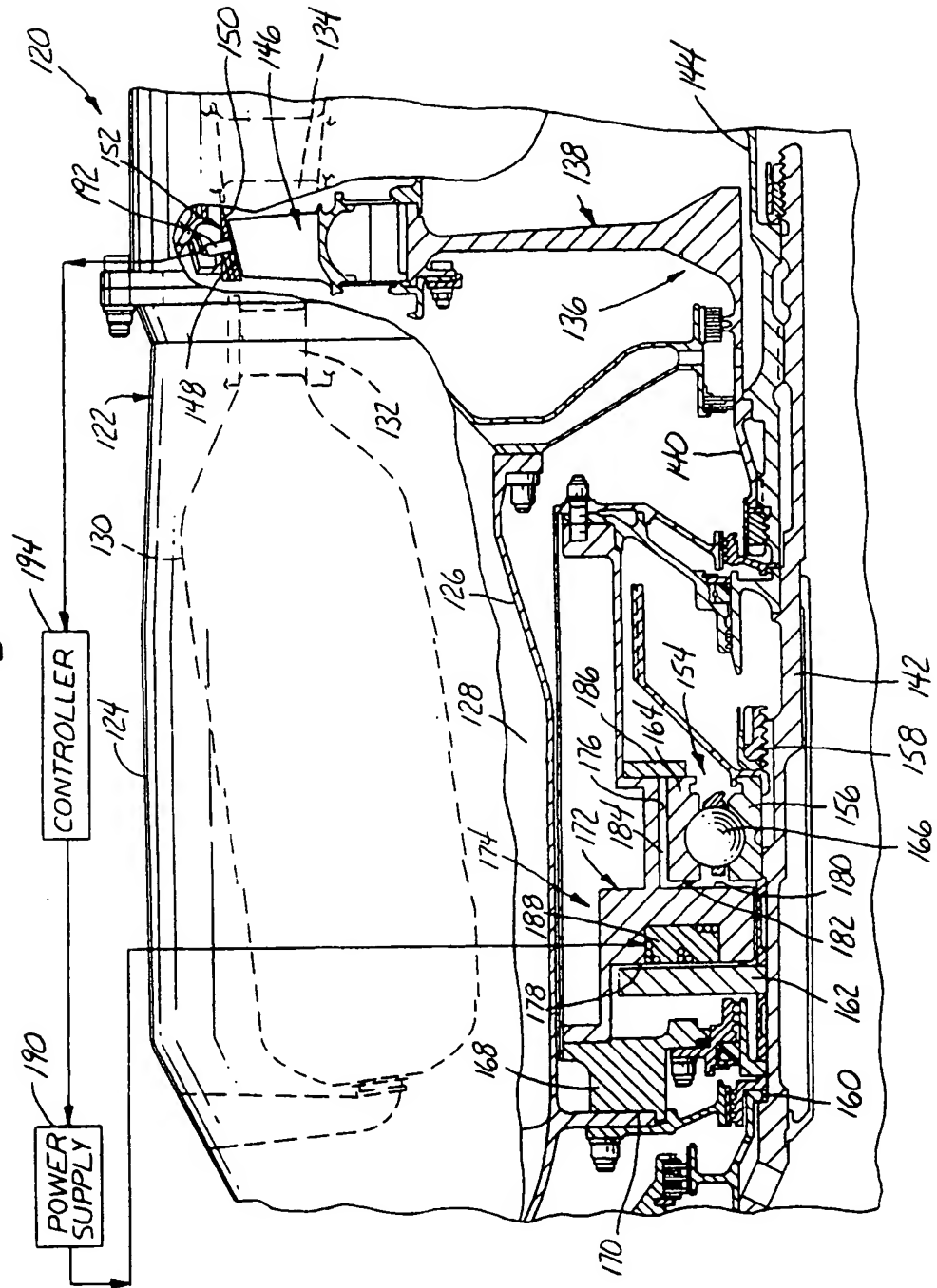


Fig. 2.





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EUROPEAN SEARCH REPORT

Application Number

EP 93 20 0119

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	WO-A-8 700 360 (H.GRIEPENTROG) * abstract *	1	F01D11/08
Y	---	2-4	
Y	GB-A-770 375 (A.ROESCH) * page 3, line 43 - line 63; figure 4 *	2-4	
A	---	1	
A	EP-A-0 317 946 (ASEA BROWN BOVERI) * abstract *		
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A	FR-A-2 339 762 (MASCHINENFABRIK AUGSBURG-NURNBERG A.G.)		
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A	EP-A-0 221 300 (KLEIN, SCHANZLIN & BECKER)		
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A	FR-A-1 364 037 (SOCIÉTÉ DE EXPLOTATION DES MATÉRIELS HISPANO-SUIZA)		

The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			F01D F16C
Place of search THE HAGUE		Date of completion of the search 28 SEPTEMBER 1993	Examiner CRIADO Y JIMENEZ, F.
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